

Dynamic measurements near the lambda-point in a low-gravity simulator on the ground

U. E. Israelsson^a, D. M. Strayer^a, T. C. P. Chui^a, M. Larson^a, and R. V. Duncan^b

^aJet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Drive, Pasadena, CA 91109

^bSandia National Laboratory, Albuquerque, NM 87185

The properties of liquid helium very near the lambda-transition in the presence of a heat current has received recent theoretical and experimental attention. In this regime, gravity induced pressure effects place severe constraints on the types of experiments that can be performed. A new experiment is described which largely overcomes these difficulties by magnetostrictively cancelling gravity influences in the helium sample with a suitable magnetic coil. Design limitations of the technique and a discussion of proposed experiments is presented.

1. INTRODUCTION

Recent investigations of the influence of an applied heat current on the properties of helium near the superfluid transition have revealed many new phenomena¹. Agreement with theories based on mean field calculations and dynamic renormalization group theory calculations is not good^{2,3}. The disagreement may stem from the fact that theories assume zero-gravity conditions, while experiments are performed in a one g environment. To overcome the influence of gravity on properties near the transition in a heat current, large values of heat current are required, which may have detrimental effects on the very properties under study. If a column of helium is held sufficiently close to the transition temperature, superfluid will coexist with normal helium. The interface between the two phases has a width determined by correlation effects and by the magnitude of heat current passing through the interface. In the presence of a heat current, heat transport on the superfluid side is accomplished by thermal counterflow of the normal and superfluid components. This counterflow velocity field is nearly a conjugate variable to the order parameter of the superfluid, thereby in principle affecting the very nature of the

transition. It has been predicted that imposition of a counterflow velocity will change the properties of the transition from continuous to first order².

The experimental situation would be much improved if measurements can be performed in a reduced gravity environment. Lower heat currents can then be used, and the interface between the normal and superfluid phases would attain more macroscopic dimensions, which would facilitate probing this region. We are presently designing an experiment which utilizes magnetostriction to oppose gravity generated pressure variations in a small column of liquid helium near the lambda-point.

2. MAGNET DESIGN

Ginzburg and Sobyenin⁴ were the first to point out that a suitably shaped magnetic field gradient can be used to counteract gravity induced pressure variations in helium. This is due to the fact that helium has a non-zero diamagnetic susceptibility. To exactly cancel gravity in a column of liquid oriented vertically in earth's gravity field a magnetic field profile as shown in equation 1 is needed.

$$B^2 = 2g\mu_0 z / (\delta\chi/\delta\rho) \quad (1)$$

Here χ is the susceptibility, μ_0 is the permeability of vacuum, z is the vertical coordinate, and ρ is the density. Near the lambda-point, the proportionality constant equals $43 \text{ T}^2/\text{cm}$. Such a field profile has the features of a moderate gradient at fields above 6 Tesla and very large gradients at fields below 6 tesla. In order to cancel gravity over a vertical region on the order of 1 cm it is necessary to operate in the high field, low gradient region. In our design efforts we chose to limit the maximum field to 9 tesla which is within the capability of NbTi wire. A feasible design for the magnet was generated numerically by allowing the size and location of a set of three coils to vary in order to best fit the required field profile. One of the three coils was wound in the opposite sense in order to help produce the (larger) field gradient at the low-field end of the design. A current density of $30,000 \text{ A/cm}^2$ was used in all three coils. The design was targeted to cancel gravity over a 0.8 cm vertical height on-axis with a field at the bottom of 7.7589 tesla and a field at the top of 5.0794 tesla. The final design produced the required field profile to within 0.08% over the entire interval and would reduce gravity to 10 mg or below over a 0.7 cm height. A schematic is shown below.

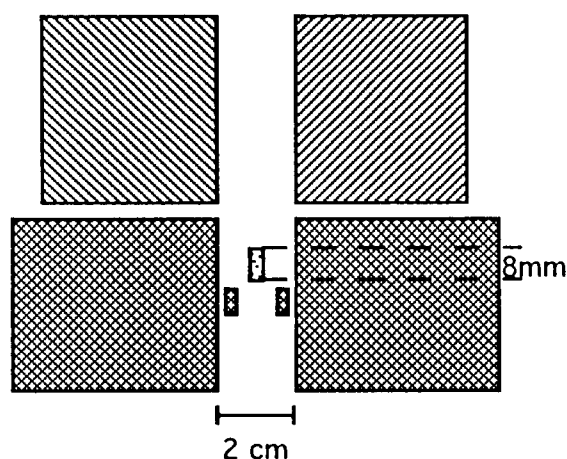


Figure 1. Magnet design for opposing gravity induced pressure effects over a 0.8 cm tall column of helium. The upper coil is wound in the opposite sense to the two lower coils.

Calculations of the leading order field terms off-axis were performed using Mathematica. It was found that the column diameter must be limited to $\sim 0.2 \text{ cm}$ in order to preserve the required gravity cancellation.

3. PLANNED EXPERIMENTS

We are currently constructing an instrument probe to perform investigations of heat current effects near the lambda-point. The primary experiment emphasis will be on attempting to observe the predicted change in character of the lambda-transition from continuous to first order when a heat current is applied². It is predicted that supercooling of the transition in a helium sample will occur by the amount $T - T_\lambda = 4.43 \times 10^{-5} \times Q^{0.744} \text{ (K)}$, where the heat current, Q , is in units of mW/cm^2 . This amount of supercooling can be related to a physical size, s , corresponding to the vertical location from the top of the cell where the interface instantaneously appears as the cell temperature is slowly reduced. The result in cm is: $s = 34.8 \times Q^{0.744} \times g/a$, where g/a is the effective gravity environment in the cell. By reducing gravity to $0.01g$, as appear feasible, a relatively modest heat current of 10^{-8} W/cm^2 would produce a supercooling size of 0.62 cm, which can be easily detected by one melting curve thermometer.

4. ACKNOWLEDGEMENTS

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4. REFERENCES

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